REMARKS

This amendment is filed in response to the Office Action dated April 19, 2005. In view of this amendment, this application should be allowed and the case passed to issue.

No new matter is introduced by this amendment. The amendment to claim 1 is supported by claims 4 and 6. Support for the amendment to claim 15 is found in claim 17. Claim 21 supports the amendment to claim 19. Claims 2 and 17 are amended to correct informalities. Claims 5, 6, 17, and 21 are amended to maintain consistency with the independent claims from which they depend. New claim 23 is supported by claim 1, as originally filed. Support for new claims 24 and 27 is found in the specification at page 19, lines 10-16. Originally filed claim 15 supports new claim 25. New claim 26 is supported by originally filed claim 19. New claim 28 is supported by claims 1, 4, and 6.

Claims 1-3 and 5-28 are pending in this application. Claims 19-22 have been withdrawn from consideration pursuant to a restriction requirement. Claims 1-5 and 7-18 are rejected. Claims 6 and 17 are objected to. Claims 1, 2, 5, 6, 15, 17, 19, and 21 have been amended in this response. Claim 4 has been canceled. New claims 23-28 have been added.

Allowable Subject Matter

Claim 6 is objected to as being dependent upon a rejected base claim but would be allowable if rewritten in independent form. Claim 17 would be allowable if rewritten in independent form and to overcome the indefiniteness rejection. The Examiner explained that the closest prior art to Matsunuma et al. fails to teach the claimed structures having the specified first and second interlayer materials.

Applicants gratefully acknowledge the indication of allowable subject matter. In accordance with the Examiner's recommendations, limitations of claims 4 and 6 have been

added to independent claim 1, and limitations of claim 17 have been added to claim 15. In addition, claim 17 has been amended to overcome the asserted informalities. Applicants submit that claims 1 and 15, as amended, are in condition for allowance.

Claim Rejections Under 35 U.S.C. § 112

Claims 2 and 17 were rejected under 35 U.S.C. § 112, second paragraph, as being indefinite because the word "thin" is a relative term.

Though Applicants believe that claims 2 and 17 are definite and clear to one ordinary skill in this art, in order to advance prosecution of this application, claims 2 and 17 have been amended to address the Examiner's concerns. Applicants submit that the instant claims fully comport with the requirements of 35 U.S.C. § 112.

Claim Rejections Under 35 U.S.C. §§ 102 and 103

Claims 1, 2, 4, and 10-14 were rejected under 35 U.S.C. § 102(e) as being anticipated by Matsunuma et al. (U.S. Pat. No. 6,602,261).

Claims 5, 7-9, 15-16, and 18 were rejected under 35 U.S.C. § 102(b) as being anticipated by or, in the alternative, under 35 U.S.C. § 103(a) as obvious over Matsunuma et al.

These rejections are traversed, and reconsideration and withdrawal thereof respectfully requested. The following is a comparison between the instant invention, as claimed, and the cited prior art.

An aspect of the invention, per claim 1, is a perpendicular magnetic recording medium comprising (a) a non-magnetic substrate having a surface and (b) a layer stack formed over the substrate surface. The layer stack comprises, in overlying sequence from said substrate surface: (i) a magnetically soft underlayer, (ii) an interlayer structure for crystallographically orienting a layer of a perpendicular magnetic recording material formed thereon, and (iii) at least one

crystallographically oriented magnetically hard perpendicular recording layer. The interlayer structure comprises, in overlying sequence from a surface of said magnetically soft underlayer: (1) a first crystalline interlayer of a non-magnetic material formed in a gas atmosphere at a first pressure, and (2) a second crystalline interlayer of a non-magnetic material formed in a gas atmosphere at a second pressure greater than the first pressure. Each of the first and the second crystalline interlayers comprises a non-magnetic material selected from the group consisting of Ru, RuCr, other Ru-based alloys, CoCrRu, Ti, CoCr, CoCrPt, CoCrTa, and CoCrMo.

Another aspect of the invention, per claim 15, is a perpendicular magnetic recording medium comprising: (a) a non-magnetic substrate having a surface; and (b) a layer stack formed over the substrate surface. The layer stack comprises, in overlying sequence from the substrate surface: (i) a magnetically soft underlayer, (ii) an amorphous or crystalline seed layer, (iii) an interlayer structure for crystallographically orienting a layer of a perpendicular magnetic recording material formed thereon, and (iv) at least one crystallographically oriented magnetically hard perpendicular recording layer. The interlayer structure comprises, in overlying sequence from a surface of said magnetically soft underlayer: (1) a first crystalline interlayer of a non-magnetic material formed in a gas atmosphere at a first pressure, and (2) a second crystalline interlayer of a non-magnetic material formed in a gas atmosphere at a second pressure greater than the first pressure. Each of the first and the second crystalline interlayers comprises a non-magnetic material selected from the group consisting of Ru, RuCr, other Ru-based alloys, CoCrRu, Ti, CoCr, CoCrPt, CoCrTa, and CoCrMo.

Another aspect of the invention, per claim 28, is a perpendicular magnetic recording medium comprising (a) a non-magnetic substrate having a surface, and (b) a layer stack formed over the substrate surface. The layer stack comprises, in overlying sequence from the substrate

surface: (i) a magnetically soft underlayer, (ii) an interlayer structure for crystallographically orienting a layer of a perpendicular magnetic recording material formed thereon, and (iii) at least one crystallographically oriented magnetically hard perpendicular recording layer. The interlayer structure comprises, in overlying sequence from a surface of the magnetically soft underlayer: (1) a first crystalline interlayer of a non-magnetic material formed in a gas atmosphere at a first pressure, and (2) a second crystalline interlayer of a non-magnetic material formed in a gas atmosphere at a second pressure greater than the first pressure. The interlayer structure provides the magnetically hard perpendicular magnetic recording layer formed thereon with a hexagonal close-packed crystal lattice with a strong <0002> out-of-plane growth orientation.

Matsunuma et al. do not anticipate or suggest the claimed perpendicular magnetic recording medium because Matsunuma et al. do not disclose a layer stack comprising an interlayer structure for crystallographically orienting a layer of perpendicular magnetic recording material comprising two layers formed under different pressure atmospheres wherein each of the first and the second crystalline interlayers comprises a non-magnetic material selected from the group consisting of Ru, RuCr, other Ru-based alloys, CoCrRu, Ti, CoCr, CoCrPt, CoCrTa, and CoCrMo, as required by claims 1 and 15. As acknowledged by the Examiner, Matsunuma fails to teach the claimed structure having the specified first and second interlayer materials.

New claim 28 includes the limitations of claim 5. The Examiner acknowledged that Matsunuma et al. is silent with respect to the claimed crystalline orientation of the hcp magnetic layer. However, the Examiner contended that the structure taught by Matsunuma et al. would inherently satisfy this feature because the reference teaches using the same materials as disclosed

in the present invention. The Examiner asserted that the burden was on Applicants to show that the prior art does not necessarily or inherently possess characteristics of the claimed product.

The fact that a certain result or characteristic may occur or be present in the prior art is not sufficient.to establish the inherency of that result or characteristic. *In re Rijckaert*, 9 F.3d 1531, 1534, 28 USPQ2d 1955, 1957 (Fed. Cir. 1993). "Inherency . . . may not be established by probabilities or possibilities. The mere fact that a certain thing may result from a given set of circumstances is not sufficient." *In re Robertson*, 169 F.3d 743, 745, 49 USPQ2d 1949, 1950-51 (Fed. Cir. 1999)(citations omitted). "In relying upon a theory of inherency, the examiner must provide a basis in fact and/or technical reasoning to reasonably support the determination that the allegedly inherent characteristic necessarily flows from the teachings of the applied prior art." *Ex parte Levy,* 17 USPQ2d 1461, 1464 (Bd. Pat. App. & Inter. 1990).

The instant specification clearly teaches that merely using the same starting materials does not produce a recording medium with the same characteristics. As disclosed in the specification on pages 22-27, including Tables I, II, IV, and V, there are significant differences between the perpendicular magnetic recording medium formed with a bi-layer interlayer, wherein the upper layer is formed in higher pressure atmosphere than the lower layer, as required by claim 28. The superiority of the perpendicular recording media formed in accordance with the claimed invention is readily apparent from the data in Tables I, II, IV, and IV. Clearly, the prior art recording media would **not inherently or necessarily** possess the characteristics of the claimed product. The Examiner's assertion that the prior art process inherently meets the limitations of claim 5 is incorrect. Applicants submit that the data presented in Tables I, II, IV, and IV clearly establish that the claimed magnetic recording medium is patentably distinct.

Applicants submit that it is well known in the industry that the Co-Pd and Co-Pt superlattice structures have FCC (face-centered cubic) (111) preferred orientations if they have preferred ones, whereas, the media of claims 5, 7, and 28, have HCP structure and <0002> preferred orientations. The media of claims 5, 7, and 28 and the Matsunuma et al. media are significantly different, and are not substantially similar, as alleged by the Examiner.

The Examiner asserted that the Matsunuma et al. media inherently comprised hcp magnetic layers. This is not correct. As disclosed by Ohmori et al. (*Low Noise Co/Pd Multilayer Perpendicular Media with Granular Seed Layer*, IEEE TRANSACTIONS ON MAGNETICS, Vol. 36, No. 5, Pages 2384-2386, September 2000) (attached), perpendicular magnetic recording media with Co/Pd multilayer and Pd seed layer show an fcc (111) orientation (last 2 lines, right column, page 2384). In addition, Peng et al. (*Co/Pt Superlattices with Ultra-Thin Ta Seed Layer on NiFe Underlayer for Double-Layer Perpendicular Magnetic Recording Media*, IEEE TRANSACTIONS ON MAGNETICS, Vol. 36, No. 5, Pages 2390-2392, September 2000) (attached) teach that Co/Pt superlattices have fcc (111) oriented texture (last 6th & 7th lines, left column, page 2391.)

The media of Matsunuma et al. have Pd or Pt-based seed layers and Co-Pt or Co-Pd based magnetic recording layers featuring very thin Co layers such as 0.11 nm. Pd and Pt are FCC-structured. Co of about 0.11 nm thick in superlattice film stack is also FCC-structured. Thus, the prior art media are not inherently HCP structured, as required by claims 5, 7, and 28.

Applicants further submit that the claimed magnetic recording medium is not suggested the cited prior art.

The dependent claims, including new claims 23-27, are allowable for at least the same reasons as the respective independent claims from which they depend, and further distinguish the claimed invention.

Claim 3 was rejected under 35 U.S.C. § 103(a) as being unpatentable over Matsunuma et al. in view of Carey et al. (U.S. Pat. No. 6,835,475). This rejection is traversed, and reconsideration and withdrawal thereof respectfully requested.

Claim 3 depends from claim 1. Thus, claim 3 is allowable for at least the same reasons as independent claim 1, as Carey et al. do not overcome the deficiencies of Matsunuma et al.

Restriction

Upon the allowance of a claim directed to the perpendicular magnetic recording medium, Applicants respectfully request rejoinder and allowance of withdrawn claims 19-22, in accordance with MPEP § 821.04. Claim 19 has been amended to include limitations added to claims 1 and 15.

In view of the above amendments and remarks, Applicants submit that this application should be allowed and the case passed to issue. If there are any questions regarding this Amendment or the application in general, a telephone call to the undersigned would be appreciated to expedite the prosecution of the application.

To the extent necessary, a petition for an extension of time under 37 C.F.R. § 1.136 is hereby made. Please charge any shortage in fees due in connection with the filing of this paper, including extension of time fees, to Deposit Account 500417 and please credit any excess fees to such deposit account.

Respectfully submitted,

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Low Noise Co/Pd Multilayer Perpendicular Media with Granular Seed Layer

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***Abstract*—A granular seed layer such as Au-SiO_2 is effective in reducing medium noise in a Co/Pd multilayer perpendicular recording medium. Clear transitions up to a linear density of 300 kfci can be recorded on the perpendicular medium using a conventional merged magneto-resistive (MR) head.**

***Index Terms*—Co/Pd multilayer media, granular seed layer, perpendicular media.**

I. Introduction

PERPENDICULAR magnetic recording has been studied to overcome thermal instability in high-density recording. The major perpendicular media are Co-Cr based alloy films and Co/(Pd, Pt) multilayer films. Co/(Pd, Pt) multilayer films with large perpendicular anisotropy have been studied for application to perpendicular magnetic-recording media [1]. Though the reproducing signal of a multilayer medium is higher than that of a Co-Cr perpendicular medium, transition noise originating from inter-particle magnetic interaction is a serious problem [2], [3]. In order to reduce this noise, we have provided a seed layer for multilayer films. It is known that a noble metal (Ag, Au, Pd, Pt) seed layer is necessary to increase perpendicular coercivity [4]. We found that the inter-particle magnetic interaction and medium noise can be reduced by using a granular seed layer composed of a noble metal and a ceramic (SiO_2, Al_2O_3).

II. Experimental

Co/Pd multilayer films and seed layers were prepared on glass disk substrates at room temperature using dc (for Co) and rf (for Pd) magnetron sputtering in Ar gas at a pressure of 2 Pa. Granular seed layers were sputtered using a composite target of noble metal and ceramic. A 2-nm-thick Ti layer was deposited on the substrate as an adhesion layer and 10-nm-thick carbon was deposited as a protective layer. A lubricant was coated on the disk surface. M-H loops were measured using a vibrating sample magnetometer (VSM). Read-write tests were performed using a merged MR head designed for use at a recording density of 4 Gbit/in^2. The recording-head structure is a conventional thin film head with high magnetic-moment $Ni_{45}Fe_{55}$ films located at both sides of the recording gap, whose thickness is 0.5 μm. The recording track width and gap length are 1.2 μm and 0.25 μm, respectively. The read track width and shield-to-shield spacing are 0.9 μm and 160 nm, respectively.

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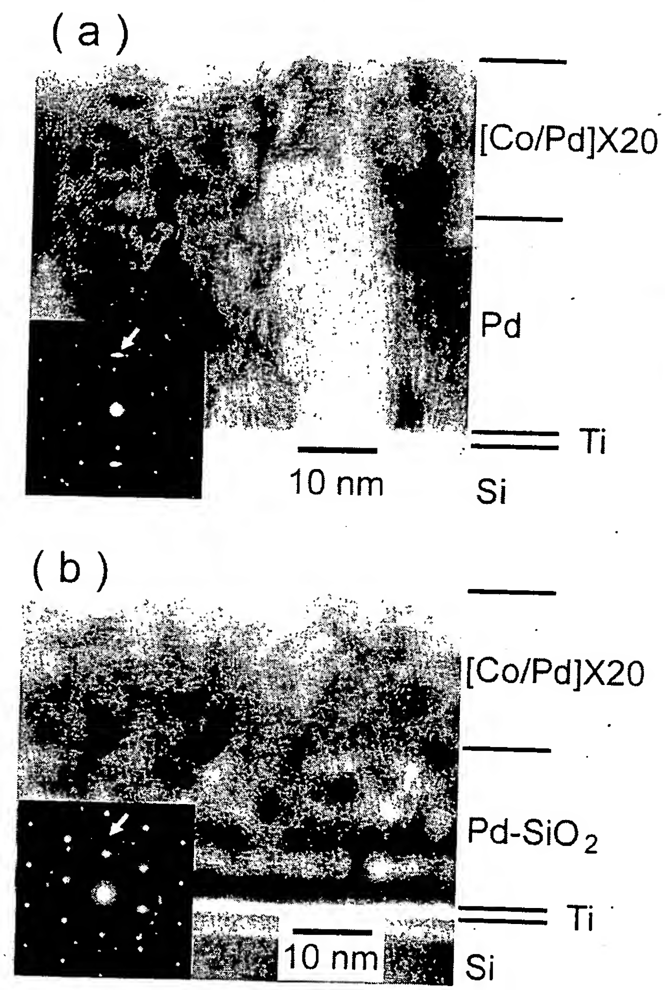

Fig. 1. Cross-sectional TEM images of Co/Pd multilayer films with seed layers of (a) Pd and (b) Pd-SiO_2.

The relative head-to-medium velocity was 5.08 m/s. The structure of the films was observed using transmission electron microscopy (TEM) and recorded patterns were observed using magnetic force microscopy (MFM).

III. Results and Discussion

A. *Magnetic properties and Film structure*

Fig. 1 shows cross-sectional TEM images and diffraction patterns of Co/Pd multilayer films with (a) a Pd seed layer and (b) a Pd-SiO_2 seed layer. The periodic spots are diffraction patterns of the Si substrate. In Fig. 1(a), the diffraction patterns of the Co/Pd multilayer and Pd seed layer show an fcc (111) orientation. In

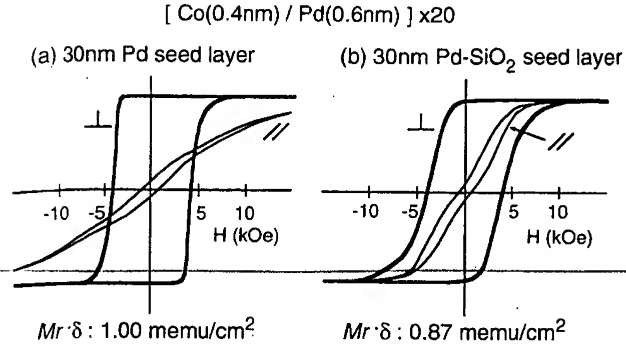

Fig. 2. M-H loops of Co/Pd multilayer films with seed layers of (a) 30 nm Pd and (b) 30 nm Pd-SiO_2.

Fig. 1(b), the Pd-SiO_2 has a granular structure and the multilayer film growing on the granular film has no preferred orientation. The grain size of the multilayer is about 5 nm. Fig. 2 shows the M-H loops for [Co(0.4 nm)/Pd(0.6 nm)]×20 multilayer films with (a) a 30 nm Pd seed layer and (b) a 30 nm Pd-SiO_2 seed layer. The coercivity (Hc) of both samples is 4 kOe. The remanence ratio (Mr/Ms) is nearly unity in each sample. Mr·δ (remanence magnetization·thickness) of the Co/Pd multilayer with the Pd seed layer is 1 memu/cm^2, and that with the Pd-SiO_2 seed layer is 0.87 memu/cm^2. By changing the seed layer to granular, the perpendicular anisotropy field (Hk) is reduced to about one-third. However, there is no perpendicular coercivity reduction because of the decreased inter-particle magnetic interaction [5].

B. Recording characteristics

In this paper, various types of Co/Pd multilayer films and seed layers are used. The thickness of the Co/Pd multilayer film is varied from 6 nm to 48 nm and the seed layer is Pd-SiO_2, Au-SiO_2, or Ag-Al_2O_3. Effects of these seed layers are similar, but a Pd-SiO_2 is effective to keep high-coercivity for thinner recording layer, and an Au-SiO_2 is better for reducing noise. The range of Hc is from 2.5 to 5.6 kOe and Mr/Ms is larger than 0.9. Commercial longitudinal hard-disk media were also used for reference. Fig. 3 shows Mr · δ dependence of reproduced signal output at recording densities of 25, 100, and 200 kfci. Signal output of perpendicular media is proportional to Mr · δ up to 1 memu/cm^2, and is almost equal to that of longitudinal media at the density of 100 kfci, with the same Mr · δ value. However, at the density of 200 kfci, signal output of the perpendicular medium is larger than that of the longitudinal medium, especially in the high Mr · δ region.

In the following studies, [Co(0.4 nm)/Pd(1 nm)]×30 multilayer with 30 nm Au-15 mol%SiO_2 seed layer was used for the perpendicular medium. For this medium, Mr · δ = 1.2 memu/cm^2, $Hc_\perp$ = 5.0 kOe, Hk = 6.7 kOe, Mr/Ms =0.97. Fig. 4 shows the magneto-motive force (MMF) dependence of signal output and overwrite for this medium. Overwrite is saturated at MMF of 0.3 AT_{0-P} with overwrite 230 kfci on 30 kfci and saturated at 0.7 AT_{0-P} with overwrite 30 kfci on 230 kfci. Recording gap field is enough to overwrite though the perpendicular coercivity is high. Fig. 5 shows the recording-density response of signal amplitude at MMF of 1 AT_{0-P}. A commercial longitudinal medium used for a

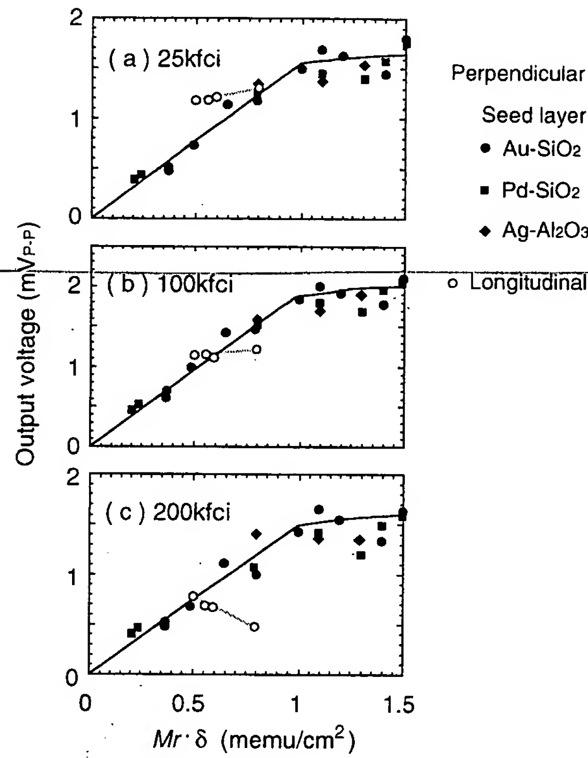

Fig. 3. Output voltage for perpendicular and longitudinal media with various Mr · δ value at a linear density of (a) 25 kfci, (b) 100 kfci and (c) 200 kfci.

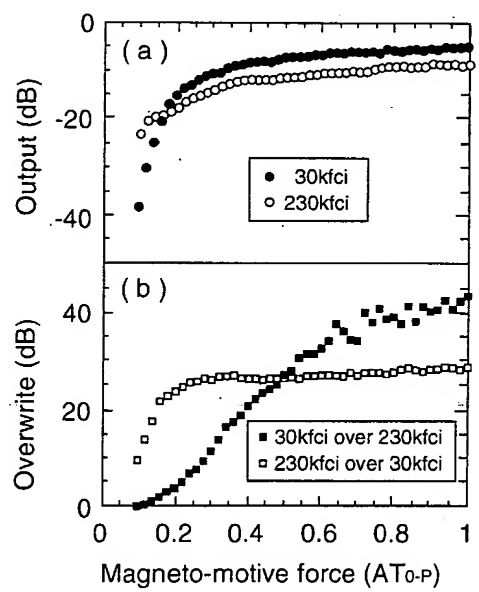

Fig. 4. Magneto-motive force dependence of (a) output and (b) overwrite for the perpendicular medium of [Co/Pd]×30 multilayer film with an Au-SiO_2 seed layer (Mr · δ = 1.2 memu/cm^2, $Hc_\perp$ = 5.0 kOe, Hk = 6.7 kOe).

10 Gbit/in^2 density disk drive, with coercivity of 3.38 kOe and Mr · δ of 0.48 memu/cm^2, was used for reference. The D_{50} value of the longitudinal medium is 240 kfci. The D_{50} value of the perpendicular medium is 270 kfci when a low-frequency signal is used as the standard, shown in Fig. 5 as D_{LF50}. However if the peak amplitude of the signal is chosen as standard, the D_{50} value decreases to 245 kfci, almost equal to that of the longitudinal medium, shown in Fig. 5 as D_{Peak50}. This value is theoretical limit of the reproducing head.

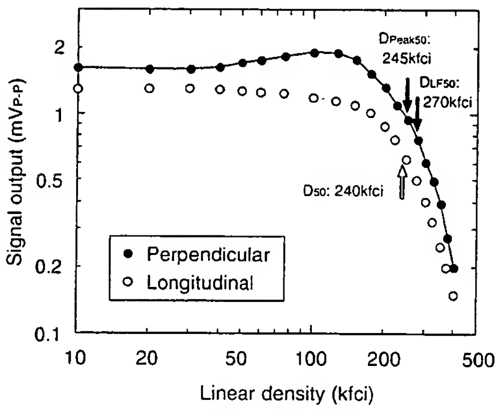

Fig. 5. Linear density dependence of signal output for the perpendicular medium (Co/Pd multilayer film with an Au-SiO_2 seed layer) and the reference longitudinal medium.

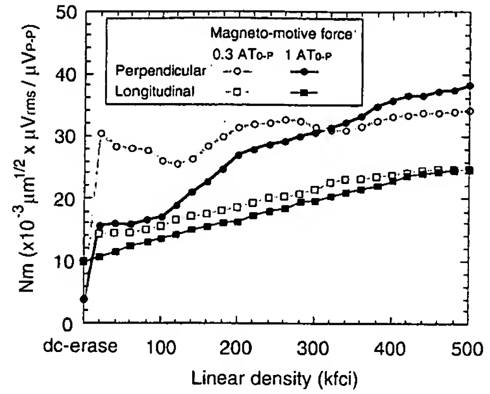

Fig. 7. Linear density dependence of medium noise for the perpendicular medium (Co/Pd multilayer film with an Au-SiO_2 seed layer) and the reference longitudinal medium.

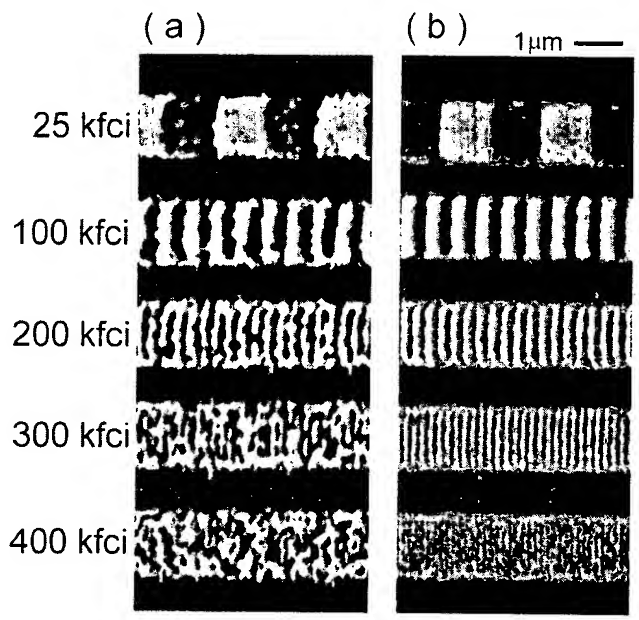

Fig. 6. MFM images of recorded paterns for Co/Pd multilayer films with seed layers of (a) Pd and (b) Au-SiO_2.

C. Recorded Patterns and Noise

Fig. 6 shows MFM images of Co/Pd multilayer films with (a) a Pd seed layer and (b) an Au-SiO_2 seed layer at the MMF of 1 AT_{0-P}. For the Pd seed layer, only up to a linear density of 200 kfci transitions are observed. For the Au-SiO_2 seed layer, clear transitions are observed up to 300 kfci. At the density of 400 kfci, transitions can be observed only in the track center. The small dots observed in the background are recorded by the leakage field of upper and lower poles, and are observed only around the recorded tracks. Fig. 7 shows the linear-density dependence of normalized medium noise by low-frequency signal amplitude and track width at magneto-motive force (MMF) of 0.3 and 1 AT_{0-P} for the perpendicular medium (Co/Pd multilayer film with an Au-SiO_2 seed layer) and the reference longitudinal medium. For the longitudinal medium, medium noise increases linearly with linear density for both MMF values. Also, for the perpendicular medium, the medium noise increases linearly with linear density at MMF of 1 AT_{0-P}. However, at MMF of 0.3 AT_{0-P}, medium noise is modulated at a frequency of 200 kfci, which corresponds to half of the recording gap. This means that medium noise increases when the perpendicular components of the recording field at the leading and trailing edges affect the medium in opposite direction, while medium noise decreases when the tow components are in the same direction. At low MMF, as the recording field cannot magnetize the medium uniformly, reverse domain noise is primary. Even at high MMF, reverse domain noise does not disappear, because medium noise at low frequency is about four times higher than that in a dc-erased state. On the other hand, in the high linear-density region, medium noise at low MMF is lower than that at high MMF. In perpendicular recording with a ring-shape head, as the recording field increases, perpendicular component of the field increases but the field gradient of the recording point loses its sharpness [6]. As the result, sufficient recording field and a sharp field gradient are missing in a ring head to be used in a perpendicular recording system.

IV. Conclusion

By using a granular seed layer, the medium noise of a Co/Pd multilayer perpendicular medium can be significantly reduced. However, it is difficult for both the reverse domain noise and transition noise to be reduced at the same time by a combination of the perpendicular medium and a conventional head. For progress in recording density, the design of the recording head must be improved.

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Co/Pt Superlattices with Ultra-Thin Ta Seed Layer on NiFe Underlayer for Double-Layer Perpendicular Magnetic Recording Media

Wenbin Peng, Oliver Keitel, R. H. Victora, Erkan Koparal, and Jack H. Judy

***Abstract*—Co/Pt superlattices with an ultra-thin amorphous Ta seed layer on a $Ni_{45}Fe_{55}$ underlayer were fabricated for double-layer perpendicular magnetic recording media using a special hard disk sputtering system with a triple-target DC magnetron cathode (Triatron). A 2.5 nm thick Ta seed layer was found to improve the crystalline structure and increase the coercivity of the Co/Pt superlattices from 1.13 to 2.17 kOe. A 2.5 nm Ta layer on a 200 nm thick magnetically soft NiFe underlayer was found to further increase the coercivity from 2.25 to 5 kOe. In addition, the sheared slope of the sides of hysteresis loop of Co/Pt superlattices was significantly improved from about 5 Gauss/Oe (with only a 2.5 nm Ta seed layer) to about 1.1 Gauss/Oe (with both a 2.5 nm Ta seed layer and a 200 nm NiFe underlayer).**

***Index Terms*—Co/Pt superlattices, double-layer perpendicular magnetic recording media, NiFe underlayer, ultra-thin amorphous Ta seed layer.**

I. Introduction

PERPENDICULAR magnetic recording is being considered as a possible candidate for extremely high density recording (EHDR) at 100 Gigabits/inch^2 and beyond. Ultra-thin multilayers of Co/Pt and Co/Pd superlattices have been developed as the perpendicular storage layer in magneto-optic recording media [1]. Such multilayers have also been investigated for perpendicular magnetic recording media because of their large interface-induced magnetic anisotropy [2], [3]. Seed layers under such superlattice multilayers have been used to improve the superlattice crystalline structure, coercivity, and squareness [4]. Efforts have also been made to use ultra-thin seed layers sputtered on a magnetically-soft NiFe underlayer to reduce the recording "spacing loss" [5].

This paper reports the first time use of a special hard disk sputtering system, with a triple-target DC magnetron uniquely-designed for co-sputtering and high-speed sequential sputtering, to fabricate multilayers of Co/Pt and Co/Pd superlattices. Ultra-thin amorphous Ta seed layers used on $Ni_{45}Fe_{55}$ underlayers for double-layer perpendicular magnetic recording media were found to significantly improve the magnetic properties of the Co/Pt and Co/Pd superlattices.

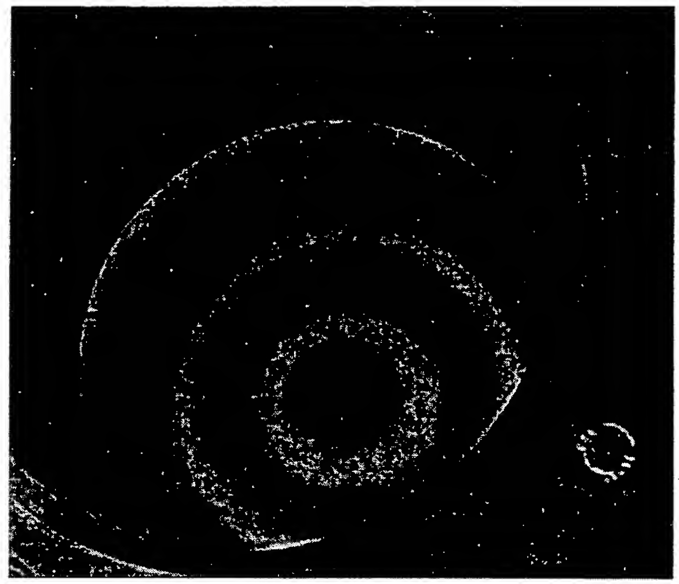

Fig. 1. Picture of the Triatron plasma rings.

II. Experiment

Co/Pt superlattices were deposited in a special hard disk commercial manufacturing sputtering system which has ten individual double-sided process modules. A special three-concentric magnetron cathode (Triatron) was used in one of the process modules for the deposition of multilayer Co/Pt and Co/Pd superlattices on magnetically-soft NiFe underlayers. Fig. 1 is a picture of the Triatron cathode surface showing the plasma rings of the center and the middle ring targets.

Most of the outer ring plasma at the left upper corner is hidden behind the shielding. The outer ring target was Co, the middle ring Pd, and the center disk Pt. Each of the ring cathodes was operated by a separate DC power supply. A fast control system operating the power supplies provides deposition times as short as 100 ms, where the material deposited was controlled by power integration over the on-time of the cathode. One bilayer sequence can be deposited within 500 ms, which allows for deposition of 30 bilayers within 15 seconds. Kr and Kr/O_2 were used as the sputtering gases. The target-to-substrate distance was set at 50 mm. The magnetically-soft $Ni_{45}Fe_{55}$ underlayer, ultra-thin amorphous Ta seed layer, and diamond-like carbon overcoats

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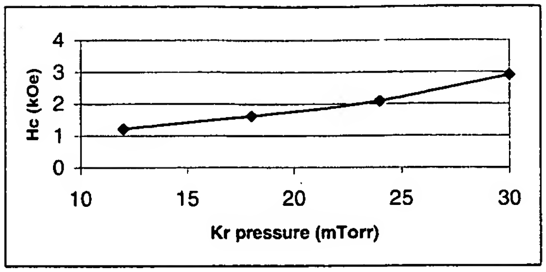

Fig. 2. Dependence of coercivity on the Kr pressure for Pt(20 nm)/13 × [Co(0.35 nm)/Pt(1 nm)]/C(10 nm).

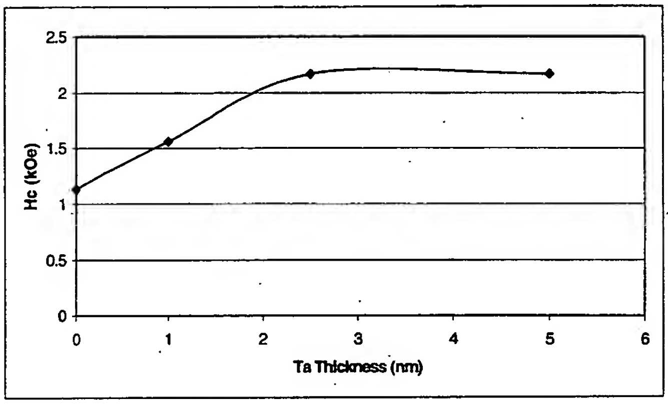

Fig. 3. Dependence of coercivity on thickness of Ta seed layer of Ta/Pt(1 nm)/13 × [Co(0.35 nm)/Pt(1 nm)]/C(10 nm). Kr pressure: 40 mTorr.

were deposited using conventional magnetron cathodes. The substrates were 95-mm diameter AlMg/NiP disks. Perpendicular hysteresis loops were measured using a polar Kerr magnetometer. The surface roughness of $Ni_{45}Fe_{55}$ underlayer was measured using an atomic force microscope (AFM).

III. Results and Discussion

The coercivity of Co/Pt superlattices can be influenced greatly by the type of gas (Kr) and the sputtering pressure. Fig. 2 shows Kr gas pressure dependence of coercivity of Pt(20 nm)/13 × [Co(0.35 nm)/Pt(1 nm)]/C(10 nm) superlattices. Larger surface-induced magnetic anisotropy and coercivity were achieved using higher sputtering gas pressures (40 mTorr instead of 12 mTorr) and heavier gas atoms which tend to reduce the recoil energy, grow sharper interfaces, and reduce magnetic intergranular interactions by inducing granular segregation [6].

Ultra-thin amorphous Ta seed layers were used for the superlattices Pt(1 nm)/13 × (0.35 nm Co + 1 nm Pt)/C(10 nm). Fig. 3 shows the dependence of coercivity on the thickness of the Ta seed layer. It can be seen that 2.5 nm thick Ta seedlayer increases the coercivity approximately by a factor of two from 1.13 kOe to 2.17 kOe. X-ray diffraction patterns indicate that the Co/Pt superlattices have fcc (111) orientated texture. Fig. 4 shows that the Co/Pt (111) peak height increased as the Ta seed layer thickness increased and reached a maximum when the thickness was 2.5 nm. Better crystalline orientation of the Co/Pt superlattices results in larger magnetic anisotropy and larger coercivity. Ultra-thin amorphous Ta seed layer can provide extremely small

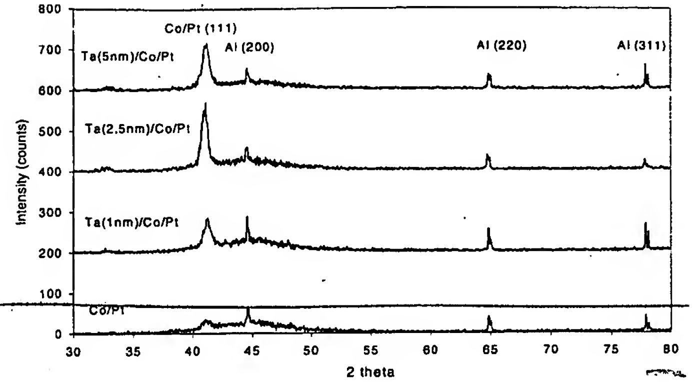

Fig. 4. X-ray diffraction patterns for Co(0.35 nm)/Pt(1 nm) with different thickness of Ta seed layers.

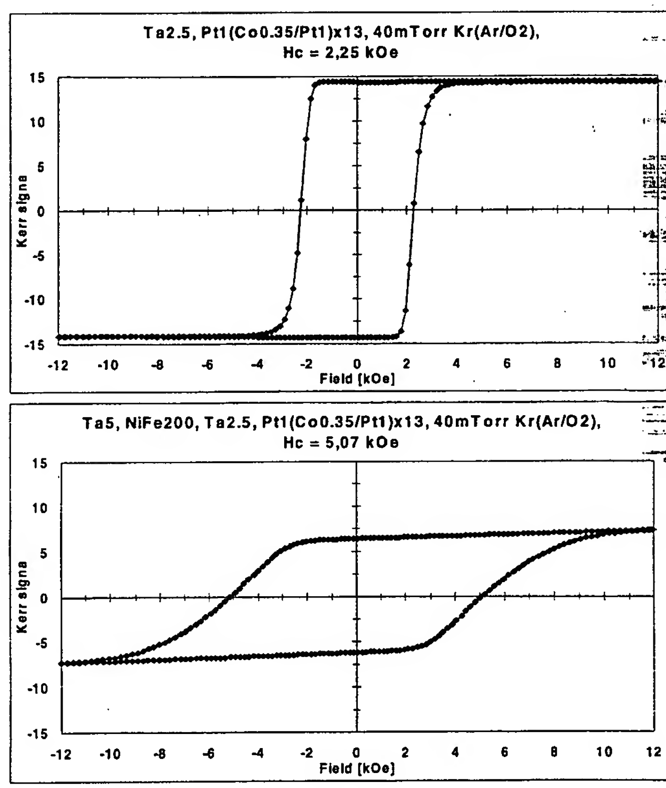

Fig. 5. Hysteresis loops of (top) Ta(2.5 nm)/ Pt(1 nm)/13 × (0.35 nm Co + 1 nm Pt)/C(10 nm) and (bottom) Ta(5 nm)/$Ni_{45}Fe_{55}$(200 nm)/Ta(2.5 nm)/Pt(1 nm)/13 × (0.35 nm Co + 1 nm Pt)/C(10 nm). The Kerr signal is in arbitrary units.

nucleation sites for the superlattices and thus may enhance preferred orientation in the columnar grain growth, which is similar with the oxide seed layers used in Co/Pd superlattice media [5]. Cross-section TEM should be done to get a better understanding of the effects of Ta seed layer.

A 200 nm thick soft $Ni_{45}Fe_{55}$ underlayer was deposited in fabricating double-layered perpendicular media. To obtain a large interface-induced perpendicular anisotropy, the underlayer must be extremely smooth. The rms roughness of a 200 nm thick $Ni_{45}Fe_{55}$ film with and without a 5 nm thick amorphous Ta seed layer was measured by AFM to be 0.9 nm with the Ta seed layer and 1.2 nm without the Ta seed layer.

To reduce the intergranular exchange coupling in the Co/Pt superlattices, Kr/O_2 was used as the sputtering gas instead of

pure Kr [3]. Fig. 5(a) shows the perpendicular Kerr hysteresis loop of Co/Pt superlattices on a 2.5 nm thick Ta seed layer. Fig. 5(b) shows the hysteresis loop of the same Co/Pt superlattices with a 2.5 nm thick Ta seed layer on a 200 nm thick $Ni_{45}Fe_{55}$ underlayer used for double-layered perpendicular magnetic recording media. It can be seen that by introducing a 200 nm $Ni_{45}Fe_{55}$ underlayer, the Co/Pt hysteresis loop coercivity increased from 2.25 to 5.07 kOe and, the side of the loop becomes much more sheared, which may indicate a reduction in the intergranular exchange coupling that could lead to lower media noise. According to VSM measurement, Ms of the Co/Pt superlattices is about 200 emu/cm^3. Thus the slope of the side of the hysteresis is about 5 Gauss/Oe in Fig. 5(a), which indicates that the superlattice is strongly exchange coupled and the switching process is dominated by domain wall motion, and about 1.1 Gauss/Oe in Fig. 5(b) which indicates a far less exchange coupling. The slope should be 1 gauss/Oe for ideal demagnetization field-induced shearing. Co/Pt superlattices were also deposited directly on $Ni_{45}Fe_{55}$ underlayer without an ultra-thin Ta seed layer in between and it was found that both the coercivity and squareness were greatly reduced. X-ray diffraction patterns indicated that the $Ni_{45}Fe_{55}$ underlayers have fcc (111) preferred orientation. The lattice mismatch between Co/Pt fcc (111) and NiFe fcc (111) is about 7%. Accordingly, well-developed columnar structure probably enhances the epitaxial growth of the Co/Pt superlattices, similar with the fact that thicker Pt seed layers can improve the coercivity of the superlattices. The ultra-thin amorphous Ta seed layer on top of the $Ni_{45}Fe_{55}$ underlayer may lead to re-nucleation of Co/Pt films to grow finer grains instead of grain-to-grain epitaxial growth on NiFe grains, which should result in higher coercivity and lower noise. Cross-section TEM will be done on the samples to confirm these speculations. Also further studies are needed to investigate the effects of effects of $Ni_{45}Fe_{55}$ underlayer.

IV. Conclusion

Ultra-thin Ta seed layers have been found to induce a better crystalline orientation and to significantly increase the magnetic anisotropy and coercivity of perpendicular Co/Pt superlattices. A NiFe underlayer with an ultra-thin Ta seed layer on NiFe underlayers for Co/Pt superlattices was shown to further increase the coercivity of the Co/Pt films as well as causing the sides of the hysteresis loop to be much more sheared which is essential for low noise double-layered perpendicular magnetic recording media.

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